APPLICATION

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FOR

HOT SUBSTRATE DEPOSITION FIBER OPTIC PREFORMS AND PREFORM COMPONENTS PROCESS AND APPARATUS

BY

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Hot Substrate Deposition Fiber Optic Preforms and Preform Components Process and Apparatus

This application claims the benefit of U.S. Provisional Application No. 60/258,494, filed December 29, 2000.

SUMMARY OF THE INVENTION

Soot deposition on a plurality of substrates for fiber optic or any other high technology applications that require very high quality water-free synthetic fused silica such as optical wave guides, lenses and prisms for the deep ultraviolet spectrum are described here. Hot Substrate Deposition (HSD) of silica for fiber optic and other applications, processes and apparatus for superior quality synthetic fused silica fiber optic preforms that can be used in the MCVD (modified chemical deposition method) and OVD (outside vapor-phase deposition), VAD (vapor-phase axial deposition) applications are also part of this invention. The process allows for deposition of fused silica preforms of doped, undoped or modulation doped, and preforms in any radial profile of the index of refraction are also part of this invention. Controlled density of the deposited material as well as the provision for a plurality of substrates leads to increased productivity and higher yield production compared to the current processes for synthetic fused silica described in numerous patents. Water-free ultrapure synthetic fused silica having desired grain size is also part of this invention. Processes and apparatus for further processing of such synthetic fused silica into rods, tubes and plates for various applications are also part of this invention.

Fused silica and possibly various dopants are either created by pyrolysis of $SiCl_4$ or other compounds or they are introduced in a powder state into a vacuum chamber that might be at vacuum or desired pressure for the particular processes. Pluralities of jet streams of fused silica are directed towards a plurality of substrates heated to certain temperatures. The particles attach themselves on the substrates and form shaped bodies of fused silica called preforms. For uniformity purposes the substrates may be rotated clockwise (CW) or counterclockwise (CCW) to move with respect to the sources of fused silica streams. Depending on the substrate temperature of the silica preforms, the preforms may have different densities and states of compaction. Very thick layers are deposited in this way without cracking or peeling from the substrates. Dopant may be added in order to alter the index of refraction of the fused silica. If continuously added, the whole preforms may be doped. If added during certain time periods, one may create desired profiles of the index of refraction. The dopant may be added as part of the silica jet stream, through the surrounding deposition atmosphere or through the porous substrate.

Such prepared soot preforms are later vitrified in situ, or they are treated separately. Quartz material, doped, undoped, or preferentially doped to achieve a certain index of refraction profile is obtained. This material is further processed into quartz tubes for fiber optics and other applications, quartz rods for fused silica wafers for semiconductors and various optical applications and quartz plates for wafer processing and optical windows.

Processes and apparatus for making of metal oxides by oxidation of metal halides, formation of fiber optic preforms, doped and undoped, and making of high quality fused silica glass are described herein. Metal oxide, silicon dioxide in particular, is deposited on controlled temperature substrates made from graphite, silicon carbide, ceramic, quartz, metal and metal alloys. The substrates are tubular or rod-like in shape, having round, rectangular or polygonal cross sections. The substrates and the deposited material are heated by means of resistive heating, RF heating or my any other means, and by any combination among them. The material

is dried, doped (if needed), and densified. The material is later converted into high quality fused silica tubes, rods or quartz plates of desired sizes.

These and further and other objects and features of the invention are apparent in the disclosure, which includes the above and ongoing written specification, with the claims and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic perspective representation of a porous preform-general chamber, which may be horizontal, vertical or any other position.

Figure 2 shows a cross-sectional view of the chamber shown in Figure 1, in which one or a plurality of deposition rods made from carbon, SiC, ceramic or graphite may be rotated to collect the glass soot.

Figure 3 is a longitudinal cross-section of the chamber showing relative longitudinal movements and rotations.

Figure 4 shows a longitudinal section of the chamber.

Figure 5 show multiple preforms with rotation and translation in the silica powder streams in the chamber.

Figure 6 shows a vitrified preform in a chamber.

Figure 7 shows a second layer of silica deposited on the vitrified silica preform.

Figure 8 shows rotating and translating the preform of Figure 7 in further powder streams and forming a cladding layer.

Figure 9 shows vitrifying and densifying a cladding layer on a core.

Figures 10A-10D show transforming a tubing into a solid member.

Figures 11A and 11B show vitrifying a silica tube and the product produced.

Figures 12A and 12B show a vitrified silica tube on a heated substrate and removed from the substrate.

Figures 13A-13D show a fiber optic preform core and a rod fabrication.

Figures 14A-14D show doped and undoped rod fabrication.

Figure 15 is a cross-sectional vertical view of forming a fused silica tubular or solid preform member, which is formed as a crystal pulled from a melted porous preform in a tubular preform forming chamber.

Figure 16 shows a tube-forming chamber with a substrate heater.

Figure 17 shows a tubular preform forming chamber, such as shown in Figure 15, with a recharging station for adding a porous preform for continuous article production. As shown in Figure 17, the deposition tube has a straight end. After the above deposition tube is aligned with the lower deposition tube and the two are rotated together, the upper deposition tube is heated by radio frequency heating of the carbon tube, or a carbon heater within the tube, to soften the inside of the cylindrical porous preform and allow the cylindrical porous preform to slide down along the aligned tubes, recharging the working preform position.

Figure 18 shows a chamber similar to that shown in Figure 17 with a substrate resistance heater.

Figure 19 shows a single unit in which the porous preform is generated around a vertical porous carbon deposition substrate. Burners are connected for vertical and radial movements to ensure the desired distance and flow from the growing porous preform. The cylindrical porous preform is transferred to the lower fused silica tubular preform-forming chamber by opening the retractable shield and heating the carbon deposition tube with radio frequency heating, so that the center of the porous preform softens and allows the preform to slide down the deposition tube. In the fused silica preform forming section, rotation is maintained at the same speed under controlled heating, and the fused silica tube is pulled from the porous preform.

Figure 20 shows chambers similar to those shown in Figure 19 with a substrate power delivery system in the lower chamber.

Figure 21 shows chambers similar to those shown in Figure 19 with an electric field generator for the soft silica flow.

Figure 22 shows a chamber with multiple heating zones for creating and melting soot and drawing a rod or tube from the melted soot.

Figure 23 shows a chamber similar to that shown in Figure 22 with an electric field generator and plasma tube surface removal.

Figure 24 shows a chamber similar to that shown in Figure 22 with an electric field generator and plasma tube surface removal.

Figure 25 shows a chamber similar to that shown in Figure 22 with an electric field generator and plasma tube surface removal with gas introduction or withdrawal within the formed tube.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention provides a controlled substrate temperature fused silica process and apparatus.

Process and apparatus for fused silica soot of desired size (doped and undoped), fiber optic preforms that are undoped, doped with the desired refractive index profile, or fully doped, fused silica tubes, fused silica fibers and rods and fused silica plates are described herein.

Figures 1 and 2 show a plurality of substrates 11 with controlled temperature housed in a vacuum chamber 1. A plurality of burners 3 for oxidation 5 of metal halides 7 such as $SiCl4$, $SiF4$ and others are either imbedded in the chamber wall 8 or they are placed inside the chamber. The proximity of the burners to the substrates 11 as well as the distance of the substrates from the center 9 of the chamber are optimized based on the number of the substrates 11, the number

of the burners 3 and their relative positions. The chamber 1 may have round, rectangular or any other suitable shape that is needed to optimize the process. Vacuum ports 13 with valves 15, vents 17 with valves 19 and a plurality of gas inlet ports 21 with valves 23 are also added to the chamber. The chamber may be vertical, horizontal, sloped and any other position or combination suitable for the new process. The chamber walls 8 may have a cooling jacket 25 for temperature control and appropriate venting apparatus for the gasses generated during the deposition. Appropriate openings are provided at one end, at each end or on one or two sides of the chamber for loading and unloading of the chamber.

A plurality of power feeds for resistive heating 29 or RF coils 31 and appropriate power feedthroughs 33 and shields 35 are also included in the chamber.

The chamber may have plurality of ports 37 for introduction of soot 39 made during another operation.

The chamber and the substrate assembly may be rotated in respect to each other clockwise or counterclockwise at certain desired speeds. Each substrate may be rotated around its axis clockwise or counterclockwise at certain desired speeds. All rotations are aimed at establishing conditions for good thickness and uniformity properties of the deposited material in the porous perform 41.

Figure 3 shows a tubular substrate 11 with deposited material 43. Each substrate 11 may be made of solid, porous or perforated material made from graphite, silicon carbide, ceramic, metal or metal alloys. It may have round, rectangular or any other cross section. It may be tubular, solid or tubular with solid core made from the same or other material. The ends 45 may have the same cross section throughout, or the ends may have different dimensions or shapes. The ends 45 may be mechanically connected to the substrate 11 or they may be part of the substrate. A gas line 47 or vacuum line may be connected with the hollow portion of each substrate having tubular shape, with or without a central rod.

Figure 4 shows an apparatus consisting of a vacuum chamber 51 having plurality of vacuum ports 53, vent lines 55, and gas ports 57 doping ports 59 for purging and doping purposes, plurality of power feedthroughs 61 with or without cooling lines 63 in them for resistive, RF 65 or any other form of heating the substrate 11 of the preform 41 and the preform itself. The chamber may have multiple heating zones 67 to accommodate the process being performed there. Rotation and translation mechanisms 60 rotate 62 and translate 64 the substrate 11 and preform 41. Slip rings 66 conduct power from source 68 to heat the substrate 11.

A preform 41 used to fabricate quartz glass tube or solid rod is shown here. The preform is vertically oriented, and the preform 41 and the quartz part being made can rotate together or independently. The tubular rod shown here is pulled downward from the preform.

In Figure 4 the dopant gases 58 surround the preform 41, and purge or dopant gases 56 from purge or dopant line 54 flow outward from the porous substrate through the porous preform 41.

In Figure 5 chamber 51 has three growing preforms 41 mounted on substrates 11, which are mounted on independent rotation mechanisms 70, which rotate the preforms with respect to each other as the support ends 45 rotate 62 and translate 64 mechanisms 70.

Figure 6 shows the vitrification of the preform 41 shown in Figure 4 to produce vitrified silica 71. The silica powder stream is discontinued, and the temperature output from the resistance or RF heaters 31 are increased to vitrification levels for the deposited silica. Rotation 62 and translation 64 of the substrate 11 are continued, while the material flows and compacts together and the preform densifies and vitrifies.

As shown in Figure 7, a second layer 73 of deposited silica may be formed over the vitrified silica 71. Several preforms 41 may be vitrified 70 and coated with a second layer 73 while relatively rotating all of the preforms with an independent rotation and support mechanism 70, as shown in Figure 5.

As shown in Figure 8, a doped or undoped cladding layer TT may be added to a doped or undoped preform core silica deposit 75. Several preforms 41 may be constructed at the same time using the independent rotation mechanism and support 70.

As shown in Figure 9, the core-forming silica layer 75 may be vitrified 76 initially before deposition of the cladding layer 77, followed by vitrification 78 of the cladding layer, all within the single chamber 51. The independent rotation mechanism 70 permits deposit and vitrification of layers on multiple preforms concurrently.

Figures 10A and 10B show cross-sections of tube-shaped preforms 41 with a hole 81, an inner tubular layer 83, and an outer tubular layer 85. Supporting the preform 41 between ends, heating the preform to softening temperature and rotating the preform shrinks the preform to the solid member 86 with a solid core 87 and cladding 89, as shown in Figures 10C and 10D.

Figure 11A shows a vitrified silica tube 90 in a chamber 51. The vitrified tube 90 is removed from the chamber, as shown in Figure 11B. Detaching the independent rotation mechanism from support ends 45 allows the substrates to be detached from the mechanism 70. Alternatively, the mechanism may be left in place on the support 45 while the individual substrates 11 are removed.

When the substrate is fused silica, the tube is ready to be used or ready to be softened and to be compacted and densified into a solid.

Alternatively, the substrate 11 may be heated, and the fused silica tube 90 may be slid off the substrate after a film is melted adjacent the substrate, after the ends 91 are removed as shown in Figures 12A and 12B.

The tubing 90 that is removed has a hole 93 and a tube wall 95, as shown in Figure 13A, before it is compressed into a solid doped fused silica rod 97, as shown in Figure 13B.

Figures 14A and 14B show fusing a doped fused silica tubing 90 to a doped fused silica rod 97.

Figures 14C and 14D show fusing an undoped fused silica tubing 90 to an undoped fused silica rod 97.

In Figure 15 a vacuum chamber 101 is oriented vertically. A preform 41 is supported vertically on its substrate 11 which has generally hemispherical ends 112. A chamber seal assembly at the top 102 of the chamber has a rotation 104 and translation 106 mechanism 103. A gas delivery system 105 with a valve 107 supplies purging or dopant gas to the hollow porous substrate. The preform has doped or undoped silica 109 having a controlled OH content. The chamber has a valved gas vent 111, a valved vacuum port 113, and a valved dopant inlet 115. Walls 117 of the chamber have appropriate heat shielding 119. Resistive or RF heating elements 121 provided in a plurality of heating zones 123 soften the silica, which flows 125. The moving silica flows around end 112 of substrate 11 as purge gas 127 flows. The resultant fused silica member, in this case tube 129, is rotated and pulled by mechanism 130 at the bottom 131 of the chamber 101.

Figure 16 is similar to Figure 15. A substrate power system 133 is added to heat the substrate 11 and to assist the heating elements 121 in softening the silica on the preform 41 to promote flow 125.

Figure 17 has a chamber 101 similar to the chambers shown in Figure 15.

A movable shelf 135 may move inward and outward 137 and up and down 139 to control doping and softening of the preform 41, and to separate the chamber 101 into two chambers 141 and 143. Lower chamber 143 has a separate set of valved ports 144, 145, 147, 149 which precisely control the conditions in the lower chamber 141. The shelf 135 divides the chamber 101 into separate heat zones 151, 153. In addition, heat outputs of heating elements 121 may be varied to create additional heat zones within zones 151 and 153.

In Figure 18 a substrate power delivery system 133 is added to control precise heating on the substrate 11. The heating elements 121 in the lower heat zone melt and flow 125 the soft

silica from the lower preform. When silica is depleted from the lower preform, heat is increased on the substrate 11 to soften the inner layer of silica, and the upper part of the preform slides downward. A new preform can be added above shelf 135.

Figure 19 shows the vacuum chamber 165, which combines a vertically oriented chamber 51 such as shown in Figure 4 used for continuous production of glass material with a tube-forming chamber 101. After the necessary material preparation steps have been made appropriate pressure and atmosphere is introduced for the glass fabrication process, tubular or solid glass material having the desired cross sectional shape is made in the upper chamber 167. The burners 3 or material feeders 37 feed material 73 as well as the glass preform 41 being made can rotate 62. A retractable shelf holder 169 is placed under the growing refill preform 41 to prevent distractions in the tube formation process in lower chamber 171. The preforms 41 might be used as produced or they may be dried, doped and densified before the fabrication of the fused silica fabrication process begins. Differentiated heat zones HZ1, HZ2, HZ3 and HZ4 control temperatures in chamber 165.

Figure 19 shows process and apparatus for continuous fabrication of fused silica glass having either tubular, solid rod having the desired cross sections. The vacuum chamber 165 may constitute a plurality of interconnected chambers similar to chamber 51 and 101. It also may be connected with a chamber for fused silica plate or bar production. Provisions for resistive or RF heating of the substrate and the preform have been included. Multiple independently controlled heating zones HZ1-HZ4 are used.

The upper chamber 167 serves for fabrication of the preform. The preform is later moved down to chamber 171 and used for continuous fabrication of fused silica glass having either tubular, solid rod having the desired cross sections. Resistive or RF heating is used to decouple the preforms from the substrates.

Figure 20 shows a chamber 165 similar to that shown in Figure 19. A plasma tube surface removal unit 173 is added to the rotating and pulling mechanism 130. A separate substrate heater 175 is added in the lower fabrication chamber.

Figure 21 is similar to Figure 20. An electric field generator 177 with electrodes 179 and 181 is added to create an electric field across the silica flow 125. Fused silica feed is softened and shaped therein. Clear, bubble free plate or bar is extracted from the chamber.

Figure 22 shows a chamber 183 for producing silica power 185 and other metal oxides from soot 187 having desired particle size. Fine oxide particles, in situ made from burners 3 or delivered through plurality of ports 37 on the chamber are heated in mass 189 and allowed to recombine. Depending on the time they stay hot and the distance the particles travel, they recombine into larger grains of desired size. The vacuum chamber 183 has multizone heating zones 21-26. Resistive heating, RF heating, plasma or other heating methods of the grains may be employed.

The soot is collected in a crucible 191 with a heater 193 and a dopant injector 195, as shown in Figure 22. It may be melted 196, funneled and flowed around a former 197 and filled with gas 199 to form a tube 201 into chamber 203.

Another chamber employing the new soot grain enlargement process for tube or rod fabrication is as shown in Figures 23 and 24. In those embodiments electric field generator 177 with electrodes 179 and 181 provide an electric field across the softened fused silica flow 125.

Figure 25 shows a double crucible 203 in the chamber. A vacuum chamber 183 having plurality of vacuum ports, gas inlet ports, vent ports, and a fused silica feed material introduction port is heated by resistance or RF heating or any other means of heating, connected through plurality of feedthroughs. A second crucible 203 made from graphite, silicon carbide, ceramic material, metal or metal alloys receives the material from the feed crucible 191, softens the same and remelts the material. A fused silica tube is produced. Pluralities of ultrasound generators are

in contact with the crucible to provide proper mixing and outgassing. Additional vacuum ports are placed above the softened material to remove any gas bubbles. The chamber can be a single chamber or plurality of chambers.

The heating of the substrate may be accomplished by separate heaters positioned axially along or in the substrate. Alternatively if resistance heating is used, the heating wire may be varied in shape, form or size along the length of the substrate. The substrate may be linear or planar and may be made in one element or plural elements. A singe control or multiple independent controls may be used. The varied heating of the substrate may be used to effect uniformity of the preform in an axial direction. Alternatively the varied heating may be used to effect varied densities or porosities of the perform along it's length or per unit area.

EXAMPLES

SILICA GLASS BODY FABRICATION

Production of synthetic fused silica glass bodies having controlled density and desired size and shape have been of interest to the natural quartz or synthetic fused silica glass industry for some time. The densities of the formed silica body mainly depend on the temperature of the flame, the distance between the substrate and the burner, and rotational and translational speeds of the substrate. Densities between 10% and 30% have been reported by this approach. The size of the body and the optimal ratio between the wall thickness (W_t) and the outside diameter (D_o), W_t/D_o, as well as the ratio between the outside diameter (D_o) and the Inside diameter (D_i), D_o/D_i, and the way the body is held during the deposition depend greatly on the density of the body surface temperature and the body density.

To overcome the current limitations and to produce large glass bodies made from synthetic fused silica, natural quartz or combination thereof, substrate heating and surface heating has been introduced. The amount of the surface heating will greatly depend on the substrate temperature, the chamber pressure, the size of the quartz particles and their temperature at impact of the surface and the size of the quartz member fabricated. Silica preforms, doped or undoped, having desired density and optimized diameter ratio can be fabricated following the examples shown below.

Example No. 1: Silica Body Fabrication

A heated substrate having temperature of about 1000°- 1400 °C is subjected to plurality of silica particle stream either generated in situ by high temperature reactions of silica precursors, or fabricated in a separate process and then introduced via ports on the chamber in pure form, doped form, mixed with neutral gas, gas plasma or combination thereof. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited, and layer by layer the silica member is formed. The silica particle stream may be doped or undoped. The temperature of the substrate might be sufficient to keep the surface of the so formed body at the same temperature. The silica body so formed is hot enough to allow for formation of a solid fused silica body. Densities between 80% and 100% may be expected as a result.

The substrate may be tubular or solid form having the desired diameter and cross section. Desired ratios between the outside and inside diameters may be obtained using this method. If tubular, the substrate may be solid or porous, depending on the dopant or reactive gas flow desired. This achieves optimized silica material-to-gas contact. The hot substrate may also serve

as a heater for the dopant gas and increased reaction time. Porous substrates can also diminish the possibility of gas bubbles entrapment near the surface of the substrate.

Substrate and surface temperatures between about 700°C and 1600°C may result in various silica densities from 10% to 100%. Controlling the fused silica body temperature by controlling the substrate and surface temperature may result in control of the pore size and pore density in the material. If the variation is in the radial direction, exposure to dopant gas over periods of time will result in radial gradient of the dopant distribution. By doing so silica members having radially graded indexes of refraction may be fabricated.

If the substrate is other than a silica core, doped or undoped made from fused silica or natural quartz; the resulting silica member may be in tubular form or may be in solid form after collapsing the tube.

Employing non uniform substrate heating along the length of the body, one may obtain a silica member having variable density over its length.

Example No. 2: Doped and Undoped Layer Combination Silica Body Fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited, and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for about 0.3 to 6 hours at temperature of about 800-1400 °C, the silica material is doped.

Step 3. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. A vitrified tubular silica body having desired wall thickness is formed.

Step 4. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 5. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped other wall OW_t desired wall thickness is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the wall thicknesses of the doped and undoped portion of the tubular member, e.g., 1:2, 1:3, 1:5, etc.

Example No. 3: Doped non-porous and undoped porous layer combination silica body fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves

on the substrate. Subsequent particles deposit on the material already deposited, and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for about 0.3-6 hours at temperature of about 800-1400 °C, the silica material is doped.

Step 3. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. A vitrified tubular silica body having desired wall thickness is formed.

Step 4. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the wall thicknesses of the doped and undoped portion of the tubular member, e.g., 1:2, 1:3, 1:5, etc.

Example No. 4: Undoped core and Fluorine doped cladding fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by

layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 4. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for about 0.3-6 hours at temperature of about 800-1400 °C, the silica material is doped.

Step 5. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 6. The substrate is transferred out of the deposition chamber area, and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed.

Step 7. The so formed silica member is collapsed and a solid rod like silica member is formed. Undoped core (high index of refraction material) surrounded by fluorine doped cladding (low index of refraction material) having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length.

Example No. 5: Doped core and Fluorine doped cladding fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica and dopant particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica

member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 4. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for about 0.3-6 hours at temperature of about 800-1400 °C, the silica material is doped.

Step 5. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 6. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted, and the substrate is removed.

Step 7. The so formed silica member is collapsed and a solid rod like silica member is formed. Undoped core (high index of refraction material) surrounded by fluorine doped cladding (low index of refraction material) having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross section and size can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length.

Example No. 6: Doped core and Fluorine doped graded index of refraction cladding fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica and dopant particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 4. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for T_1 hours at temperature of 800-1400 °C, the silica material is doped. T□ is about 0.3 to 2 hours.

Step 5. The substrate and/or chamber temperature is raised to about 1400-1500 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body

having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 6. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The o accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 7. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_2 > T_1$ hours at a temperature of about 1100°C-1400 °C, the silica material is doped. T_2 is about 0.4 – 4 hours.

Step 8. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 9. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 10. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_3 > T_2$ hours at temperature of about 1100 °C - 1400°C, the silica material is doped. T_3 is about 0.5 – 5 hours.

Step 11. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 12. The so formed vitrified tubular silica body is heated to temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 13. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_4 > T_3$ hours at temperature of about 1100°C - 1400 °C, the silica material is doped. T_4 is about 0.6 to 6 hours

Step 14. The substrate and/or chamber temperature is raised to 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Steps 15-17. Repeat Steps 12-14 while further reducing the exposure to gaseous dopant, SiF4 in this case.

Step 18. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed.

Step 19. The so formed silica member is collapsed and a solid rod like silica member is formed. Undoped core (high index of refraction material) surrounded by graded index of refraction fluorine doped cladding (low index of refraction material) having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross section and size can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length.

Example No. 7: Doped core having graded index of refraction and Fluorine doped graded index of refraction cladding fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica and dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams and reduced dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 4. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 5. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams and further reduced dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. Porous silica body having about 25-35% solid glass density is obtained by this process.

Step 6. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 7-9. Repeat steps 4-6 further reducing the dopant levels in the deposited silica by lowering the dopant concentrations in the dopant particle streams, etc.

Step 10. The so formed vitrified tubular silica body is heated to temperature of 1300 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. Porous silica body having 25-35% solid glass density is obtained by this process.

Step 11. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for T_1 hours at temperature of about 1100^0c - 1400 °C the silica material is doped. T_1 is about 0.3 to 2 hours.

Step 12. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 13. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. Porous silica body having about 25-35% solid glass density is obtained by this process

Step 14. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_2 > T_1$ hours at temperature of about 1100 °C – 1400^0C the silica material is doped. T_2 is about 0.4 to 4 hours.

Step 15. The substrate and/or chamber temperature is raised to about 1400-1500 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 16. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 17. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_3 > T_2$ hours at temperature of about 1100 °C – 1400°C the silica material is doped. T_3 is about 0.6 to 6 hours.

Step 18. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 19. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having 25-35% solid glass density is obtained by this process.

Step 20. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and/or the chamber into the deposited porous silica material for $T_4 > T_3$ hours at temperature of 1100^0C-1400 °C, the silica material is doped. T_4 is about 0.6 to 6 hours

Step 21. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified and a tubular silica body having desired doped inner wall thickness IW_t and undoped outer wall OW_t desired wall thickness is formed.

Step 22-24. Repeat Steps 12-14 while further reducing the exposure to gaseous dopant, SiF4 in this case.

Step 25. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed.

Step 26. The so formed silica member is collapsed and a solid rod like silica member is formed. Undoped core (high index of refraction material) surrounded by graded index of refraction fluorine doped cladding (low index of refraction material) having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length. The radial distribution of the index of refraction in the core and the cladding will depend on the thickness of the doped layer deposited and on the pore density in the as deposited preform.

Example No. 8: Doped core having graded index of refraction and fluorine doped cladding having graded index of refraction fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica and dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle stream and reduced concentration dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 4. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 5. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams and further

reduced concentration dopant particle stream introduced via ports on the chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 6. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 7-9. Repeat steps 4-6 further reducing the dopant levels in the deposited silica by further lowering the dopant concentrations in the dopant particle stream. Repeat until the desired index of refraction profile in radial direction is obtained.

Step 10. The so formed vitrified tubular silica body is heated to a temperature of about 1380 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 80-90% fused silica density is obtained by this process.

Step 11. The so formed silica body is heated to a temperature of about 1370 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 75-85% solid glass density is obtained by this process.

Step 12. The so formed vitrified tubular silica body is heated to temperature of 1360 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 65-75% fused silica density is obtained by this process.

Step 13. The so formed vitrified tubular silica body is heated to a temperature of about 1330 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 50-60% fused silica density is obtained by this process.

Step 14. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 15. Introducing silicon tetra fluoride, SiF_4, through the chamber into the deposited porous silica material for about 0.3 - 6 hours at temperature of 1100^0C - 1400°C the silica material is doped. The amount of the SiF_4 penetrating the cladding will be proportional to the pore density and the exposure time at given temperature of the preform.

Step 16. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired cladding layer wall thickness is formed. Repeat until the desired index of refraction profile in radial direction is obtained.

Step 17. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed.

Step 18. The so formed silica member is collapsed and a solid rod like silica member is formed. Undoped core (high index of refraction material) surrounded by graded index of refraction fluorine doped cladding (low index of refraction material) having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length. The radial distribution of the index of refraction in the core and the cladding will depend on the thickness of the doped layer deposited and on the pore density in the deposited preform.

Example No. 9: Fluorine doped cladding having graded index of refraction fiber optic preform fabrication using prefabricated doped or undoped core rod

Step 1. Prefabricated silica doped or undoped rod is heated to a temperature of about 1400 °C and is subjected to plurality of silica particle streams introduced via ports on the

chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 90-100% fused silica density is obtained by this process.

Step 2. Prefabricated silica doped or undoped rod is heated to a temperature of about 1380 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 80-90% fused silica density is obtained by this process.

Step 3. The so formed silica body is heated to a temperature of about 1370 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 75-85% solid glass density is obtained by this process.

Step 4. The so formed vitrified tubular silica body is heated to a temperature of about 1360 °C and is subjected to plurality of silica particle stream introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 65-75% fused silica density is obtained by this process.

Step 5. The so formed vitrified tubular silica body is heated to a temperature of about 1330 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 50-60% fused silica density is obtained by this process.

Step 6. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 7. Introducing silicon tetra fluoride, SiF_4, through the chamber into the deposited porous silica material for about 0.3 –6 hours at temperature of about 1100^0 - 1400 °C the silica material is doped. The amount of the SiF_4 penetrating the cladding will be proportional to the pore density and the exposure time at given temperature of the preform.

Step 8. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The newly deposited porous silica is vitrified, and a tubular silica body having desired cladding layer wall thickness is formed. Repeat until the desired index of refraction profile in radial direction is obtained.

Step 26. The so formed silica member is vitrified and a solid rod like silica member is formed. Doped or undoped core (high index of refraction material) surrounded by graded index of refraction fluorine doped cladding (low index of refraction material) having desired diameter

and length is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the core diameter and the outside cladding layer diameter of the fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication fiber optic preforms that are up 6 inches or more in diameter and several meters in length. The radial distribution of the index of refraction in the core and the cladding will depend on the thickness of the doped layer deposited and on the pore density in the as deposited preform.

Example No. 10: Process for fabrication of fluorine doped cladding tube having graded index of refraction fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1400 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 90-100% fused silica density is obtained by this process.

Step 2. Prefabricated silica doped or undoped rod is heated to a temperature of about 1380 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 80-90% fused silica density is obtained by this process.

Step 3. The so formed silica body is heated to a temperature of about 1370 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 75-85% solid glass density is obtained by this process.

Step 4. The so formed vitrified tubular silica body is heated to a temperature of about 1360 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 65-75% fused silica density is obtained by this process.

Step 5. The so formed vitrified tubular silica body is heated to a temperature of about 1330 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 50-60% fused silica density is obtained by this process.

Step 6. The so formed vitrified tubular silica body is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the

silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 7. Introducing silicon tetra fluoride, SiF_4, through the porous substrate and the chamber into the deposited porous silica material for about 0.3 - 6 hours at temperature of about 1100^0C - 1400 °C, the silica material is doped. The amount of the SiF_4 penetrating the cladding will be proportional to the pore density and the exposure time at given temperature of the preform.

Step 8. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate. The porous silica is vitrified and a tubular silica body having desired cladding layer wall thickness is formed.

Step 9. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the inner diameter and the outside diameter of the tubing fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication doped tubing for fiber optic preforms that are up 12 inches or more in diameter and several meters in length. The radial distribution of the index of refraction in the cladding will depend on the thickness of the doped layer deposited and or the pore density in the as deposited preform.

Example No. 11: Doped core having graded index of refraction for fiber optic preform fabrication

Step 1. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica and dopant particle streams introduced via ports on the chamber. The accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% solid glass density is obtained by this process.

Step 2. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 3. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams and reduced concentration dopant particle stream introduced via ports on the chamber. The so accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 4. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 5. Rotating and translating, a substrate consisting of porous tubing is heated to a temperature of about 1300 °C and is subjected to plurality of silica particle streams and further reduced concentration dopant particle stream introduced via ports on the chamber. The

accelerated particles collide with the substrate and deposit themselves on the substrate. Subsequent particles deposit on the material already deposited and layer by layer the silica member is formed. A porous silica body having about 25-35% fused silica density is obtained by this process.

Step 6. The substrate and/or chamber temperature is raised to about 1400-1600 °C while rotating the substrate and maintained there for certain time interval. A vitrified tubular silica body having desired wall thickness is formed.

Step 7-9. Repeat steps 4-6 further reducing the dopant levels in the deposited silica by further lowering the dopant concentrations in the dopant particle stream. Repeat until the desired index of refraction profile in radial direction is obtained.

Step 10. The substrate is transferred out of the deposition chamber area and the substrate is removed. If wetting between the substrate and silica occurs, the substrate is heated to the softening point of the silica. The contact between the substrate and the silica member is melted and the substrate is removed.

Step 11. The so formed silica member is collapsed and a solid rod like silica member is formed. Graded index of refraction core having desired diameter and length is formed. The duration of the silica deposition for certain substrate cross sections and sizes can be adjusted to allow for various ratios between the inner diameter and the outside diameter of the tubing fiber optic preform, e.g., 1:2, 1:3, 1:5, etc. The length of the chamber and the translation capabilities can provide basis for fabrication doped cores for fiber optic preforms that are up 12 inches or more in diameter and several meters in length. The radial distribution of the index of refraction in the cladding will depend on the thickness of the doped layer deposited and on the pore density in the deposited preform.

While the invention has been described with reference to specific embodiments, modifications and variations of the invention may be constructed without departing from the scope of the invention, which is defined in the following claims.